Low noise 1.2 THz SIS receiver

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Abstract —We present the development of a low noise SIS mixer for the 1.1-1.25 THz heterodyne receiver of FIRST space radiotelescope. The quasi-optical SIS mixer has two NbTiN/AlN/Nb junctions with critical current density 30 kA/cm². The individual junction area is close to 0.65 μm². The SIS junctions are coupled to the optical input beam through a planar double slot antenna and a Si hyperhemispherical lens. The minimum DSB receiver noise temperature is 650 K, about 12 hν/k.

I. Introduction

In the last decade, SIS receivers using Nb/AlOx/Nb junctions and superconducting Nb circuits have become the best practical solution for the ground-based radio astronomy at mm and submm wavelengths [1]. The minimum submm SIS receiver noise is only three times above the quantum limit [2]. This type of ultra low noise receiver is needed to cover the upper part of the atmosphere transparency band accessible to ground-based radio astronomy facilities. The upper frequency limit of these SIS receivers is determined by the gap frequency of Nb (f_{gap}=0.65-0.7 THz) due to the loss in the Nb circuit. Another frequency limit at about 1.7 f_{gap} =1.0 THz-1.1 THz is due to the cancellation of the quantum assisted tunneling when approaching $2f_{gap}$.

SIS mixers at frequencies over 1 THz are needed for sensitive receivers for airborne and space observatories. This motivates research on alternative materials for low loss THz circuits as well as new types of SIS junctions having a higher gap frequency.

Recent progress in thin film NbTiN technology [3] has given the possibility to create low loss circuits above 0.6-0.7 THz and to improve the performance of the SIS mixers with Nb/AlOx/Nb junctions up to 1 THz [4, 5]. Another approach, using a low loss normal metal circuit to build a low noise 1.05 THz SIS mixer, has been demonstrated in [6, 7].

The introduction of the NbTiN/AlN/Nb SIS junctions along with NbTiN circuits allows a substantial improvement of the SIS mixer operation up to 900 GHz, with the minimum noise within a factor of ten of the quantum limit [8]. The gap voltage of the existing NbTiN/Nb/AlN/NbTiN junction is about 3.4 mV, potentially allowing the extension of SIS mixer operation above 1.4 THz.

The goal of our work is to extend the low noise performance of the SIS receivers into the THz band using the NbTiN technology. Our approach to build a low noise 1.1-1.25 THz SIS mixer is to use a NbTiN/AlN/Nb tunnel junction with a high critical current density and a low loss circuit made of normal metal and superconducting thin films in a quasi-optical mixer design.

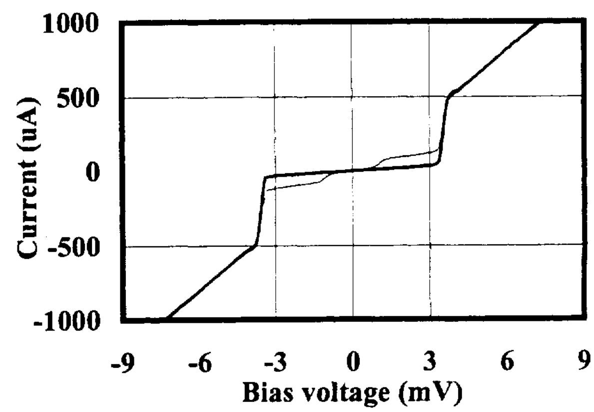

Fig. 1. Current-Voltage characteristic of the NbTiN/AlN/Nb junction with (thinner line) and without radiation at 1130 GHz. Critical Josephson current density is about 30 KA/cm².

II. SIS junction

We use NbTiN/AlN/Nb SIS junctions with critical Josephson current densities around 30 KA/cm². A current-voltage characteristic (CVC) of a two-junction array with a total area of 1.3 μm² is presented in Fig. 1. This junction has a sub-gap to normal state resistance ratio of about Rsg/Rn=12.

A sharp quantum step appears when radiation at 1130 GHz is applied (dotted line). The quantum step width is reduced from $h\nu/e$=4.8 mV to $h\nu/e-4\Delta/e$=2 mV, due to the mutual cancellation of the two quantum steps, at the positive and the negatives branches of CVC. We see only some minor traces of the hot electron effect in this device, appearing like a heating effect in a CVC of a pumped SIS junction.

III. SIS Mixer

We are using a quasi-optical SIS mixer design, similar to one described in [6]. The SIS junction with a double slot planar antenna is mounted at the Silicon hyperhemispherical lens. A polyethylene lens is used to collimate a broad (f/d=2.5) beam coming out of the hyperhemispherical lens into a beam with f/d of about 15 (Fig. 2). The SUPERMIX program [9] was used for the circuit design and optimization. We expect about 1 dB loss in the mixer circuit in the 1.1 THz – 1.25 THz range when using a NbTiN ground plane, Al wiring layer and SiO insulating layer, and around 1.5 dB loss when using a full normal metal circuit.

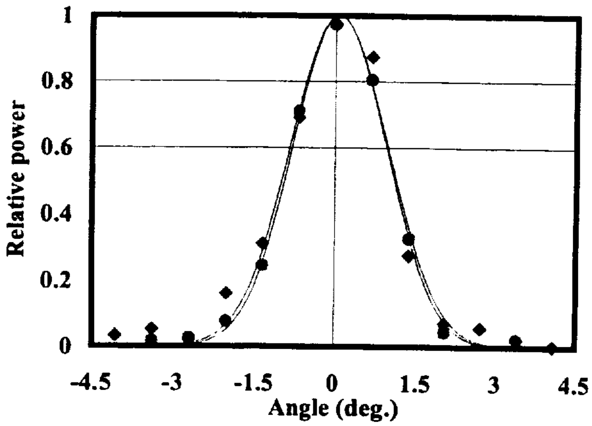

Fig. 2. The measured beam pattern of the SIS receiver at 1.13 THz. The H plane data are shown with dots, and the E plane data with diamonds. The Gaussian fits to the E and H plane data are nearly identical (solid lines) with the f/d ratio about 15 at –10 dB level.

IV. Test SIS receiver

The SIS receiver is mounted in an Infrared Laboratory HL-3 cryostat. The vacuum window is in Mylar 12 μm thick. The infrared filter at the 77 K stage of the cryostat is of Zitex. The local oscillator power is coupled to the mixer beam using a polarizing grid rotated at 45° as a 3 dB coupler.

The intermediate frequency range is 1 GHz – 2 GHz and the IF amplifier noise is about 10 K.

V. Experiment

The receiver beam pattern has been measured using the heterodyne detection of a hot black body (a heater) of a small size. The signal was modulated with a chopper and detected with a lock-in amplifier. The E and H plane measured data are presented in Fig. 2 with diamonds and dots, respectively. The measured beam is symmetrical. The Gaussian fits to the E and H data are identical within the precision of this measurement (solid lines in Fig.2). At the –10 dB level the beam f/d ratio is about 15.

The receiver sensitivity test at 1130 GHz is presented in Fig. 3. Here the solid lines present the receiver output IF power as a function of the SIS junction bias. From upper to lower, the curves are the measured data with the hot load, the cold load, and without local oscillator power. For the hot load experiment, the receiver is looking at a black body at 296 K ambient temperature. For the cold load experiment, we are using a liquid nitrogen cooled black body coupled to the receiver beam with a 3 dB coupler (polarizing grid rotated at 45°). The effective temperature of the cold load is expected to be 186 K. The receiver Y factor is 1.13 and the DSB noise temperature is 650 K. The receiver conversion gain is -13 dB.

The receiver noise may be improved using an IF amplifier with a lower noise temperature, and with a further optimization of the mixer circuit loss.

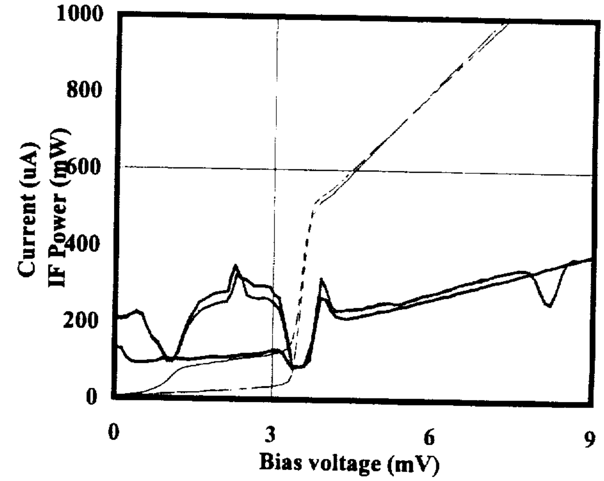

Fig. 3. SIS receiver Y factor measurement at 1.13 THz. The solid lines from upper to lower present the power at the receiver IF output: data with a hot load, with a cold load and data without local oscillator power. The dotted lines are the CVC with and without LO power. The receiver noise temperature is about 650 K. The cold load consists of the liquid nitrogen cooled load coupled via a 3 dB coupler. The hot load effective temperature is 296 K and the cold load is expected to be 186 K.

VI. Conclusion

We developed a SIS receiver for the 1.1-1.25 THz range. At 1.13 THz frequency the receiver double sideband noise temperature is about 650 K. The receiver is using a quasi-optical mixer design with a Si hyperhemispherical lens and twin NbTiN/AlN/Nb SIS junctions with a critical current density of 30 KA/cm^2.

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